Forschungsinstitut für biologischen Landbau FiBL
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Trans4Num: Exchange on SOLm and food systems modelling between CAU/CAAS & FiBL

Adrian Müller
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Online, April 10, 2024, 10.30 – 12.00

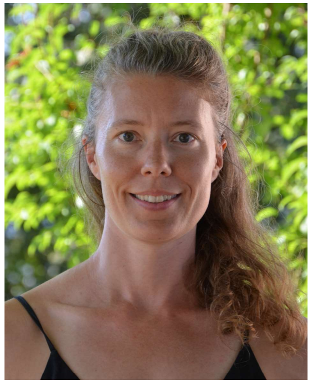
Team (all from the Department of Food System Sciences FSS)

Adrian Müller

Nina Zarrineh

Kevin De Luca

Anke Möhring



Claudia Meier

Christian Grovermann

FiBL

trans4num

Workshop Goals

- What are food system models and when and why are they used?
- What is SOLm

Workshop Outline

Wednesday April 10 2024,
10.30 – 12.00

1. Welcome & Introduction
2. Food system modelling
3. SOLm structure and data
4. Option space and scenarios
5. Policy and decision support
6. Technical details
7. Wrap up and questions

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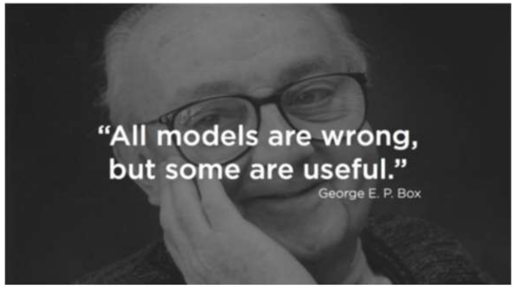
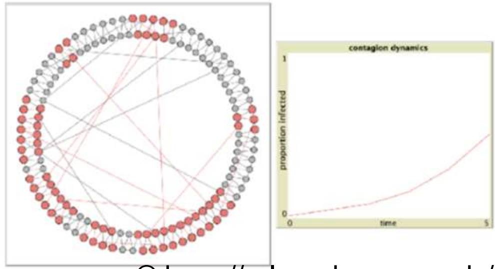
Models

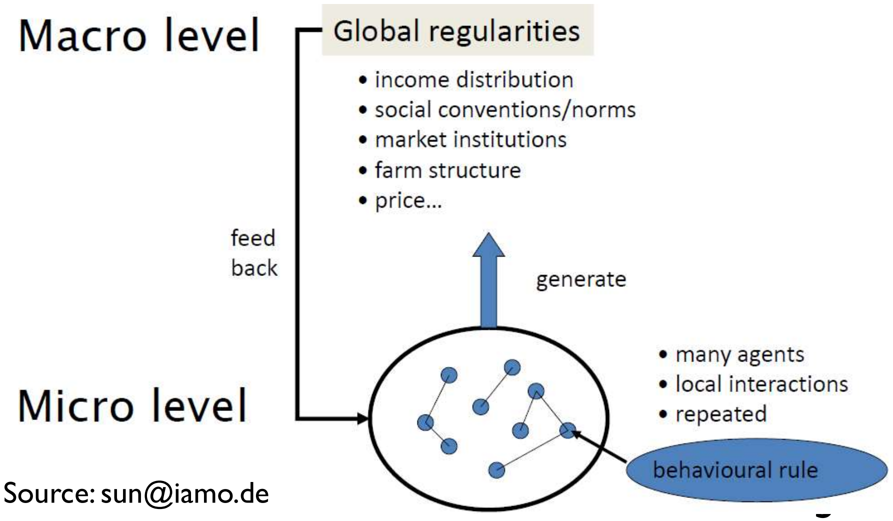




- Models are structures (abstract or physical) that can potentially represent real-world phenomena.

- "If we want to make reality and therefore truth useful to science, we must do violence the reality. … In nature, everything is equally essential. By seeking out the relationships that seem essential to us, we order the material in a surveyable way at the same time. Then we are doing science." Source: Jakob von Uexküll, 1909

- "Scientific modelling is a scientific activity, the aim of which is to make a particular part or feature of the world easier to understand, define, quantify, visualize, or simulate by referencing it to existing and usually commonly accepted knowledge".
  Source: https://en.wikipedia.org/wiki/Scientific_modelling



Source: sun@iamo.de

(Food System) Models

- Identify gross, robust relations
- A focus on trade-offs and synergies between different aspects
- Results often indicate what will be problematic, less so what will be the solution
- Use as a “boundary object” to inspire debates between various stakeholders

The way we code

- We are no data scientists
- All the more: we try to start from the characteristics of the data structure and less so from agronomic knowledge
- Coding is like writing: inspiration, the right moment to work efficiently
- Some technicalities
    - Flexible (generic code much to be specified in scenario specifications)
    - Modular
    - Functions to avoid copy-past, etc.
    - R and SQLite

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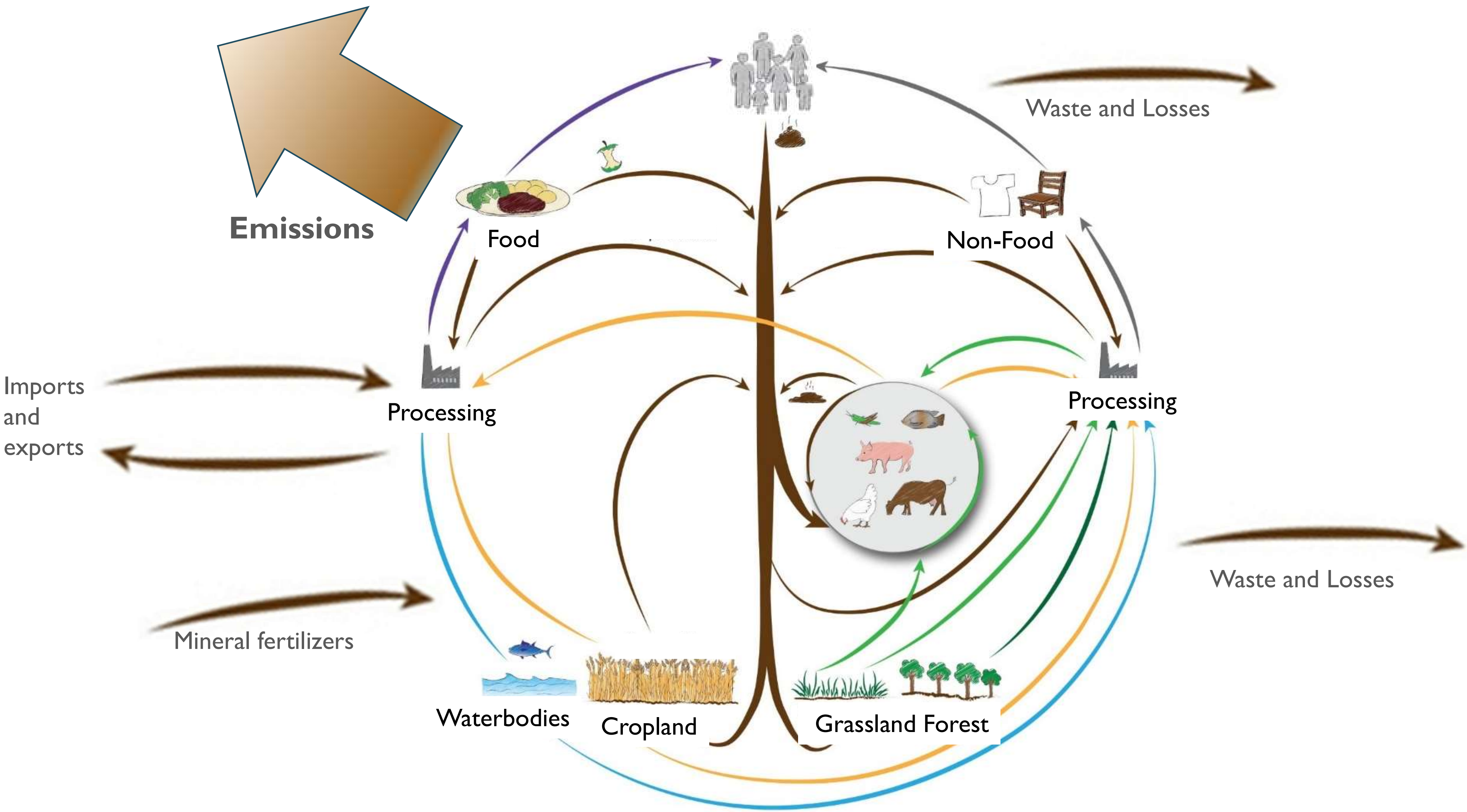
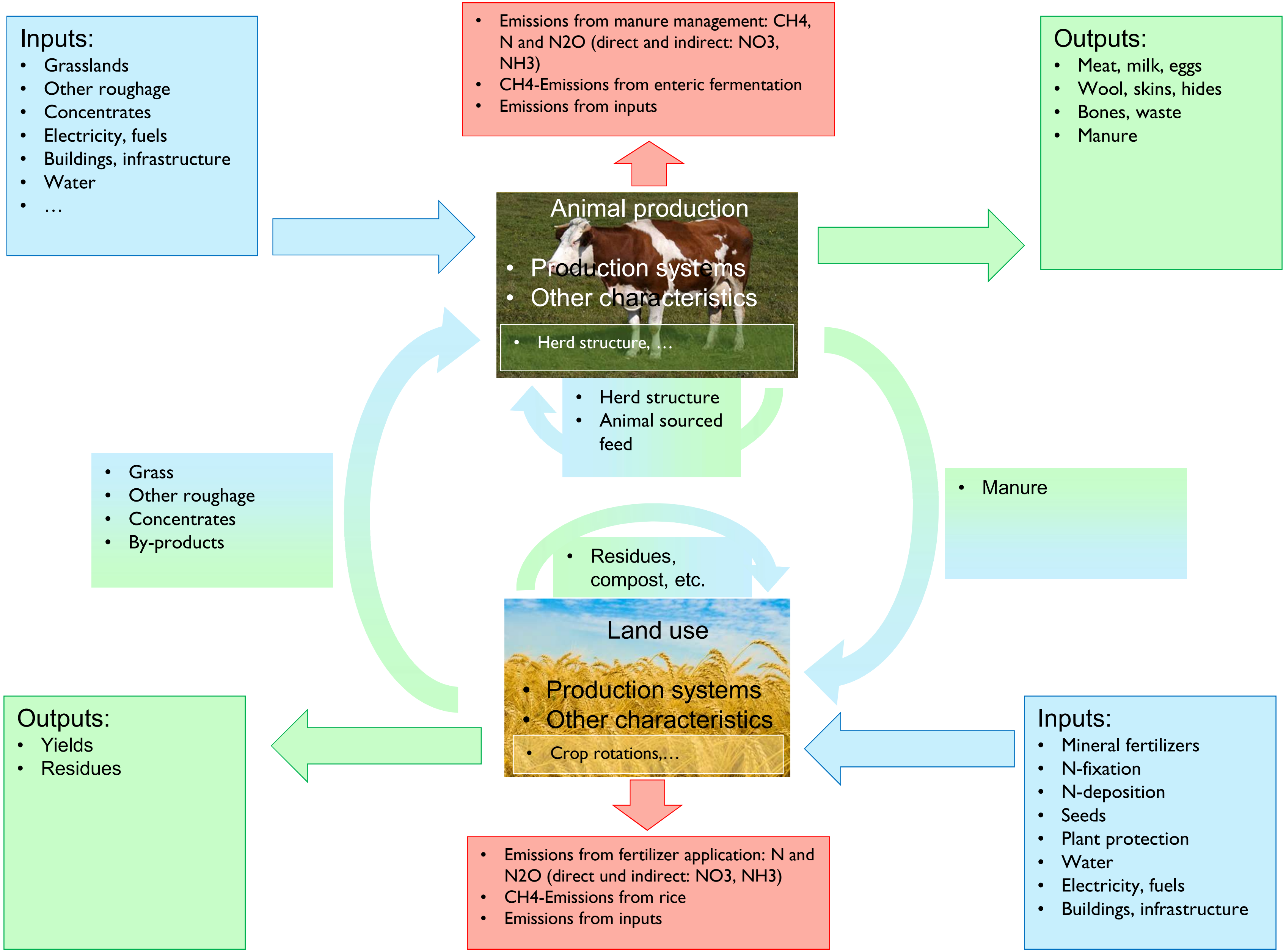
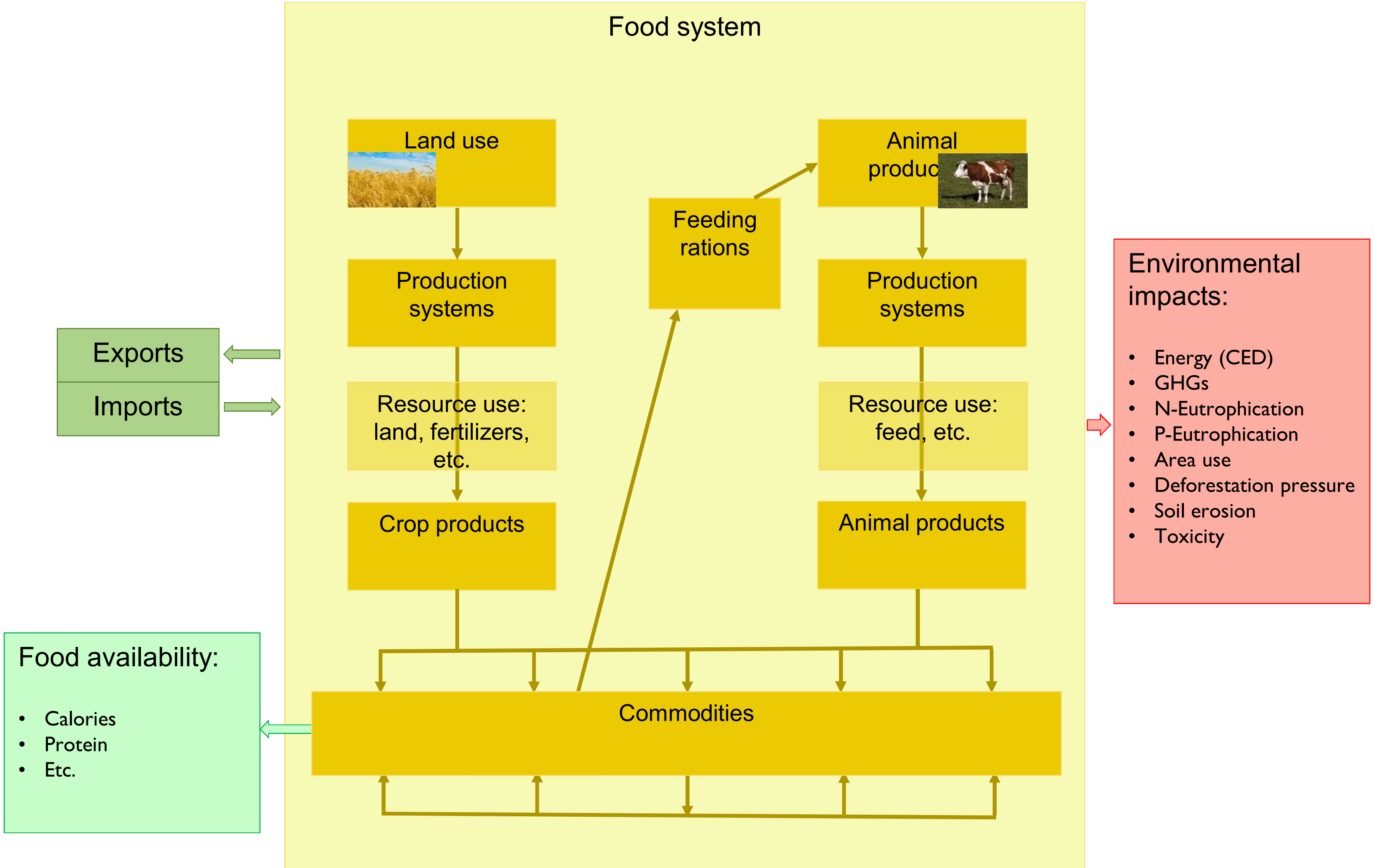
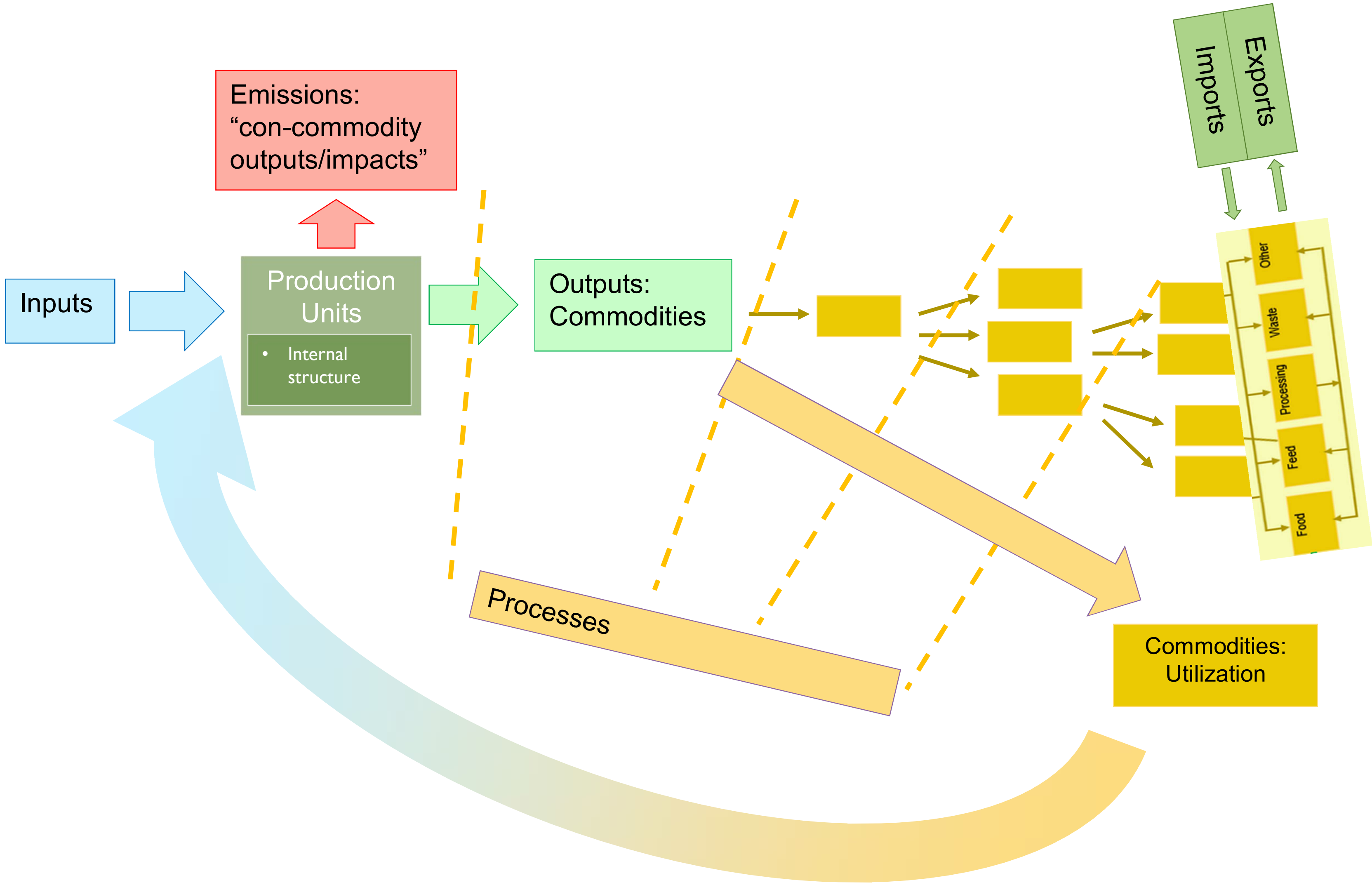
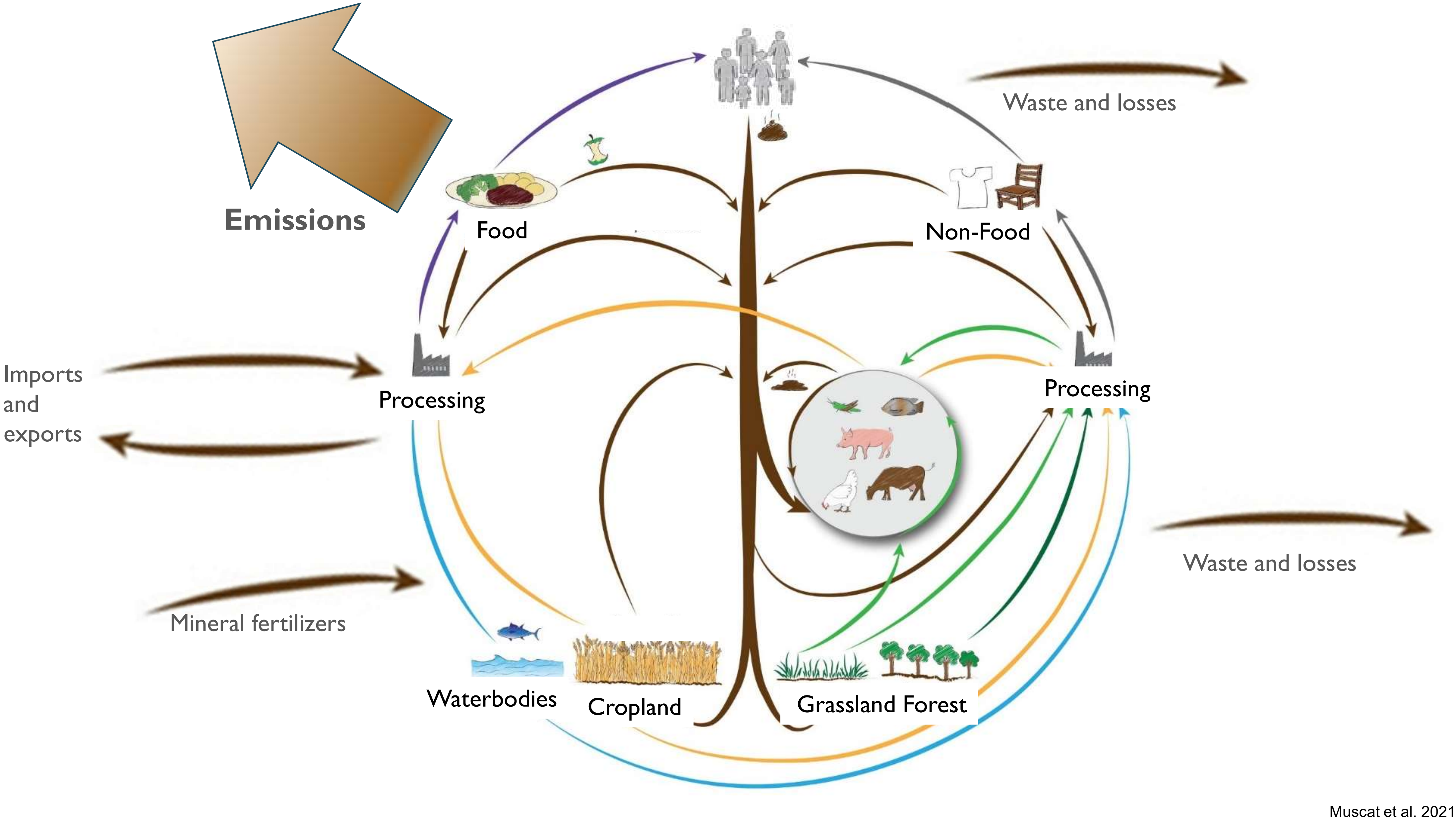


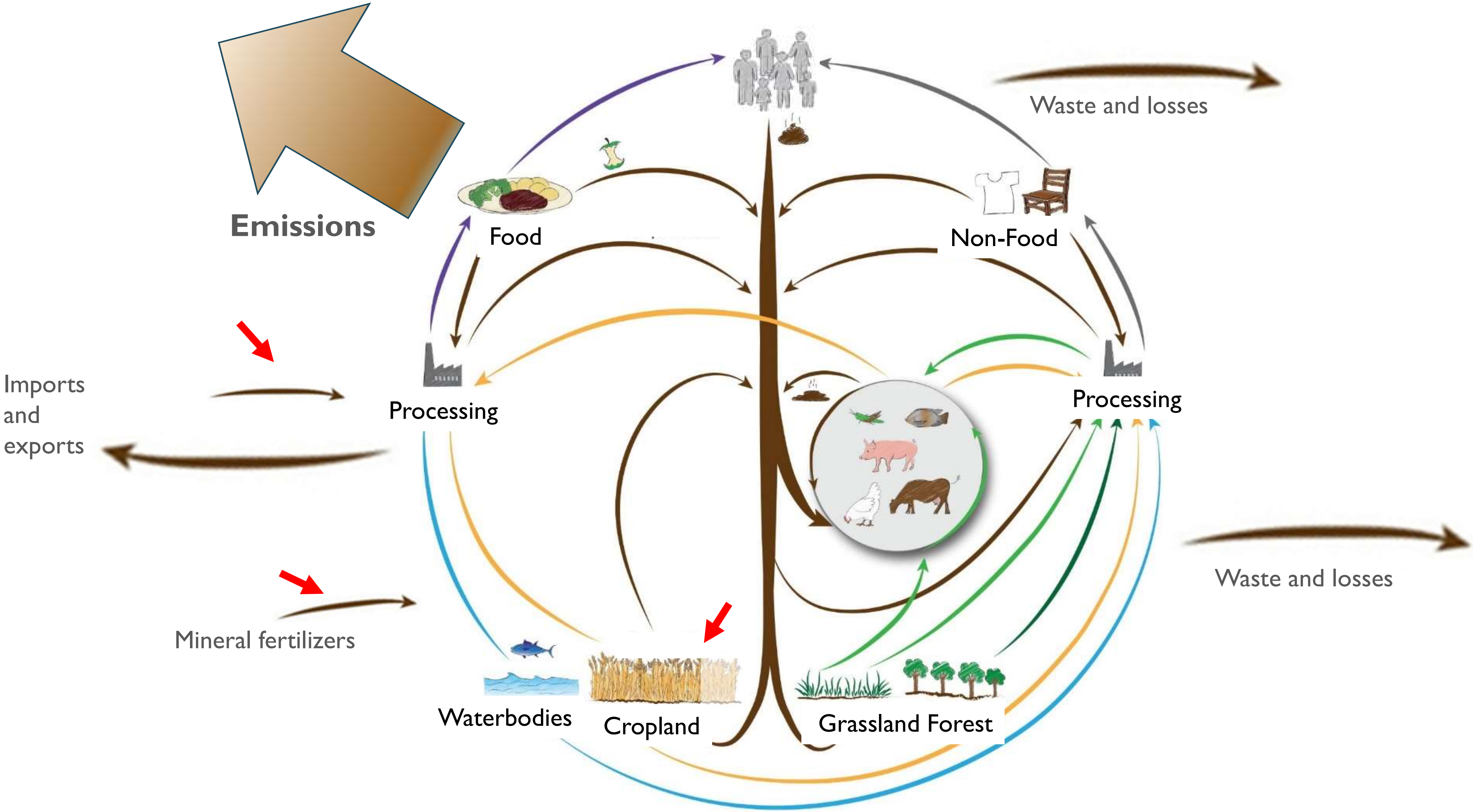
Muscat et al. 2021


Inputs:
• Grasslands
• Other roughage
• Concentrates
• Electricity, fuels
• Buildings, infrastructure
• Water
• …
• Emissions from manure management: CH4, N and N2O (direct and indirect: NO3, NH3)
• CH4-Emissions from enteric fermentation
• Emissions from inputs
Outputs:
• Meat, milk, eggs
• Wool, skins, hides
• Bones, waste
• Manure
Animal production
• Production systems
• Other characteristics
• Herd structure, …
• Herd structure
• Animal sourced feed
• Grass
• Other roughage
• Concentrates
• By-products
• Manure
• Residues, compost, etc.
Land use
• Production systems
• Other characteristics
• Crop rotations,…
Outputs:
• Yields
• Residues
Inputs:
• Mineral fertilizers
• N-fixation
• N-deposition
• Seeds
• Plant protection
• Water
• Electricity, fuels
• Buildings, infrastructure
• Emissions from fertilizer application: N and N2O (direct und indirect: NO3, NH3)
• CH4-Emissions from rice
• Emissions from inputs

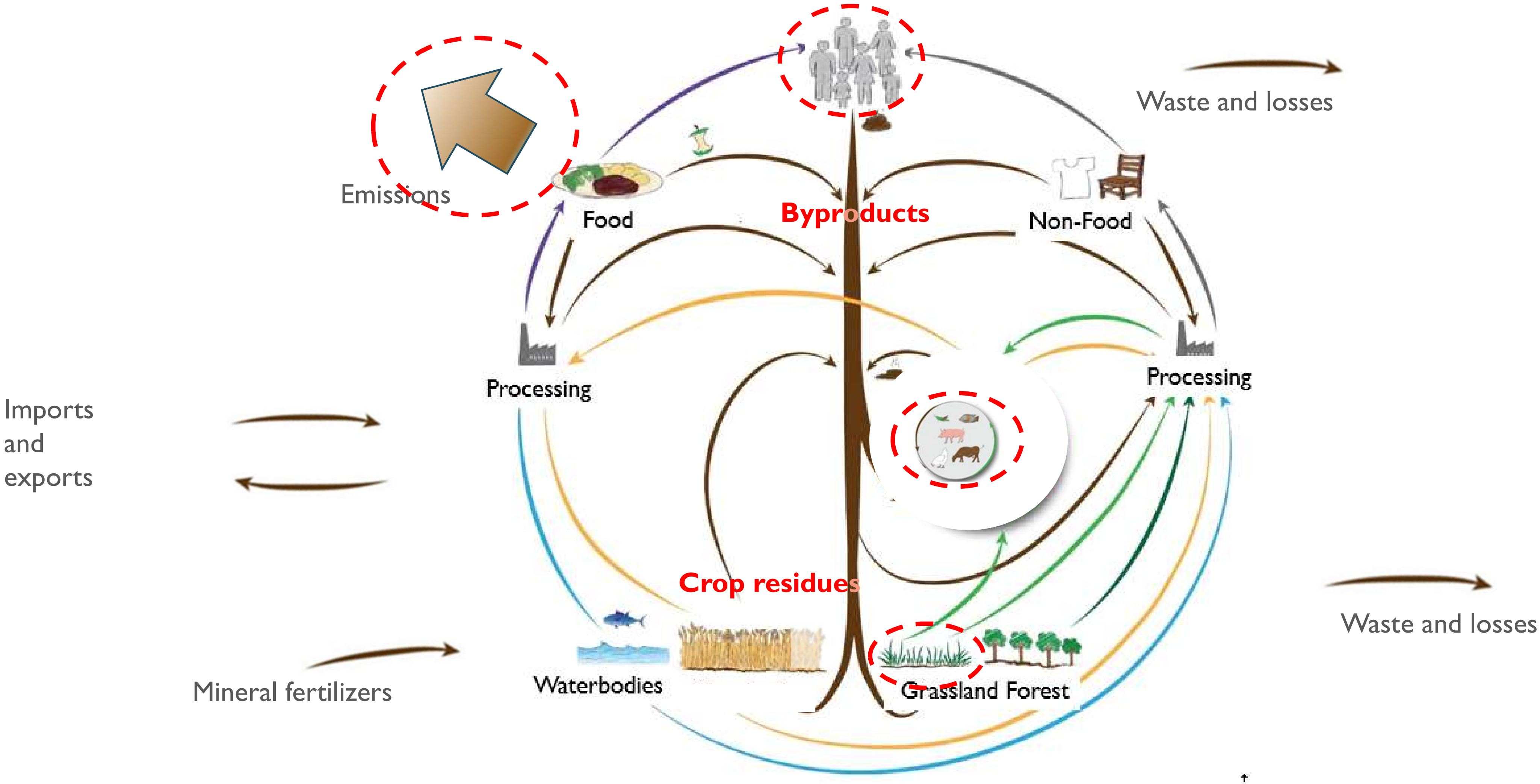

Food system
Land use
Animal production
Feeding rations
Production systems
Production systems
Exports
Imports
Resource use: land, fertilizers, etc.
Resource use: feed, etc.
Crop products
Animal products
Commodities
Food availability:
Calories
Protein
Etc.
Environmental impacts:
Energy (CED)
GHGs
N-Eutrophication
P-Eutrophication
Area use
Deforestation pressure
Soil erosion
Toxicity


Emissions:
“con-commodity
outputs/impacts”
Inputs
Production
Units
Internal
structure
Outputs:
Commodities
Imports
Exports
Other
Waste
Processing
Feed
Food
Processes
Commodities:
Utilization


Emissions
Waste and losses
Food
Non-Food
Imports
and
exports
Processing
Processing
Waste and losses
Mineral fertilizers
Waterbodies
Cropland
Grassland Forest
Muscat et al. 2021



Muscat et al. 2021



Muscat et al. 2021

SOLm structure and basic functioning

- These models trace the biomass and nutrient flows driven by
  - the internal modelling structure/equations and
  - a number of assumptions (e.g. on the parameter values on the dimensions determining the options space)
- No optimization, but driven by a social planner (advantages/disadvantages)
  - Many assumptions to be made "by hand"
    - Generally driven by "ceteris paribus" assumptions: "all else equal"
  - Baseline/calibration
  - Avoiding corner solutions
  - "realistic scenarios" vs. optimal ones
  - Multiple maxima in option spaces
  - Very flexible and detailed, etc.
  - Fast

SOLm data

- The model is fed with and calibrated by a large number of different data, e.g. from
  - FAOSTAT
  - IPCC
    - National GHG inventories
  - National nitrogen balances
  - Various publications with global datasets (e.g. erosion, gridded yield suitability data, etc.)
  - Etc.

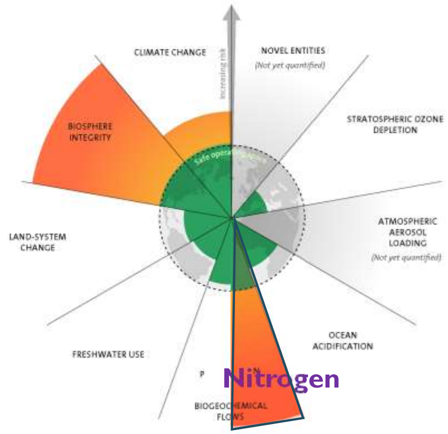
Option space and scenarios

- How to tell the stories – narratives - communication
- The bio-physical models we use allow to line out the option space of future agriculture and food systems
- The **option space** is the totality of all options that emerge from combining different levels along a number of different key dimensions, e.g.
  - Yields
  - Share of organic production
  - Level of reduction in food-competing feed for animals
  - Level of food waste reduction
  - Diets
  - GHG mitigation goals
  - Etc.

Option space and scenarios

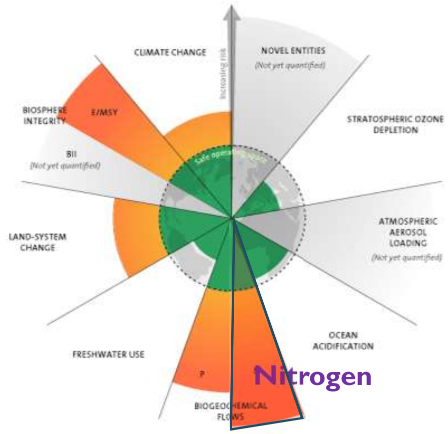
- Each option in the option space can then be assessed according to their performance regarding various indicators, such as e.g.
  - Land use
  - Deforestation
  - Nitrogen surplus
  - GHG emissions
  - Biodiversity pressures
  - etc.

2009



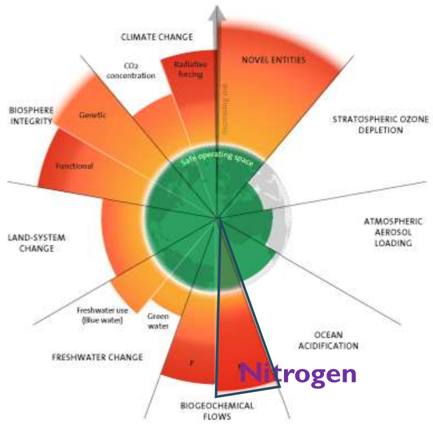
3 boundaries crossed

2015



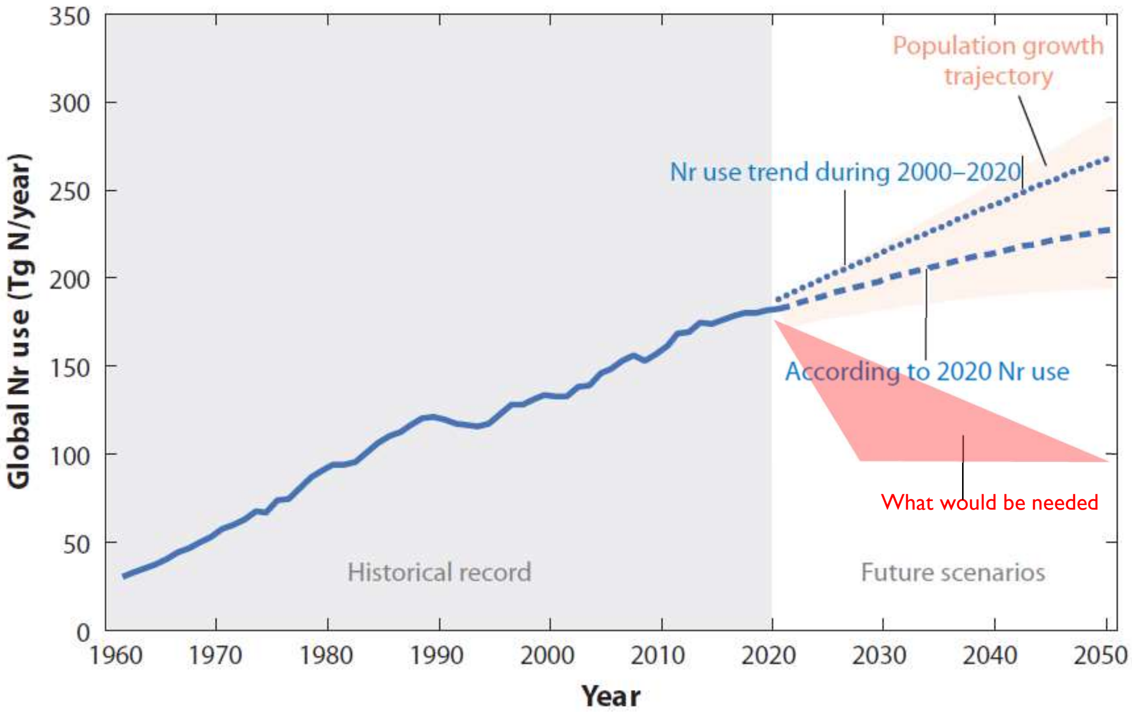
4 boundaries crossed

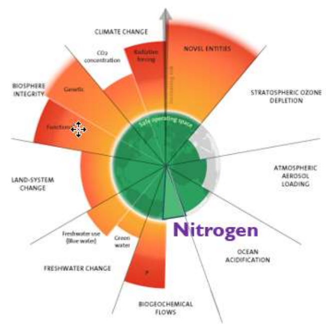
2023



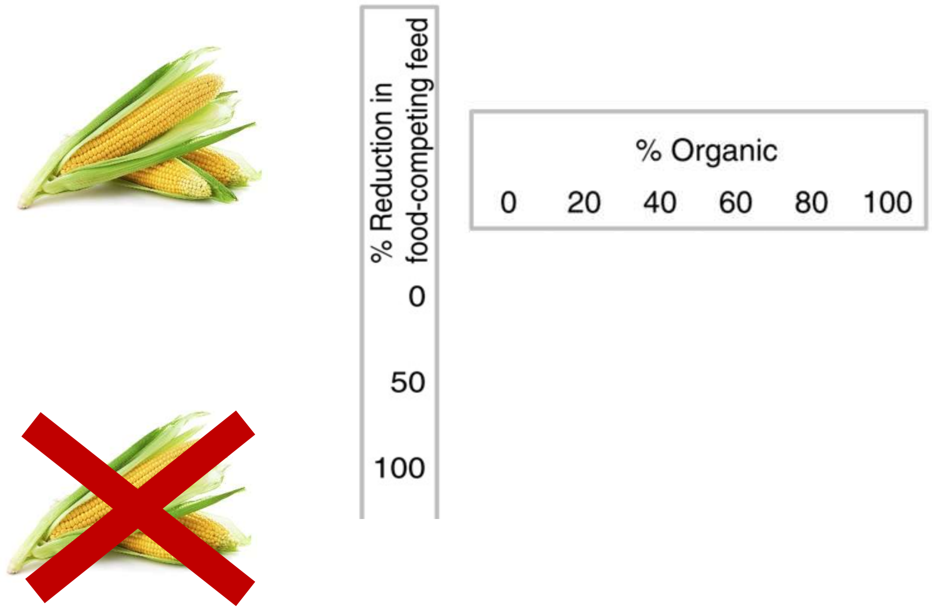
6 boundaries crossed

Stockholm Resilience Center 2023

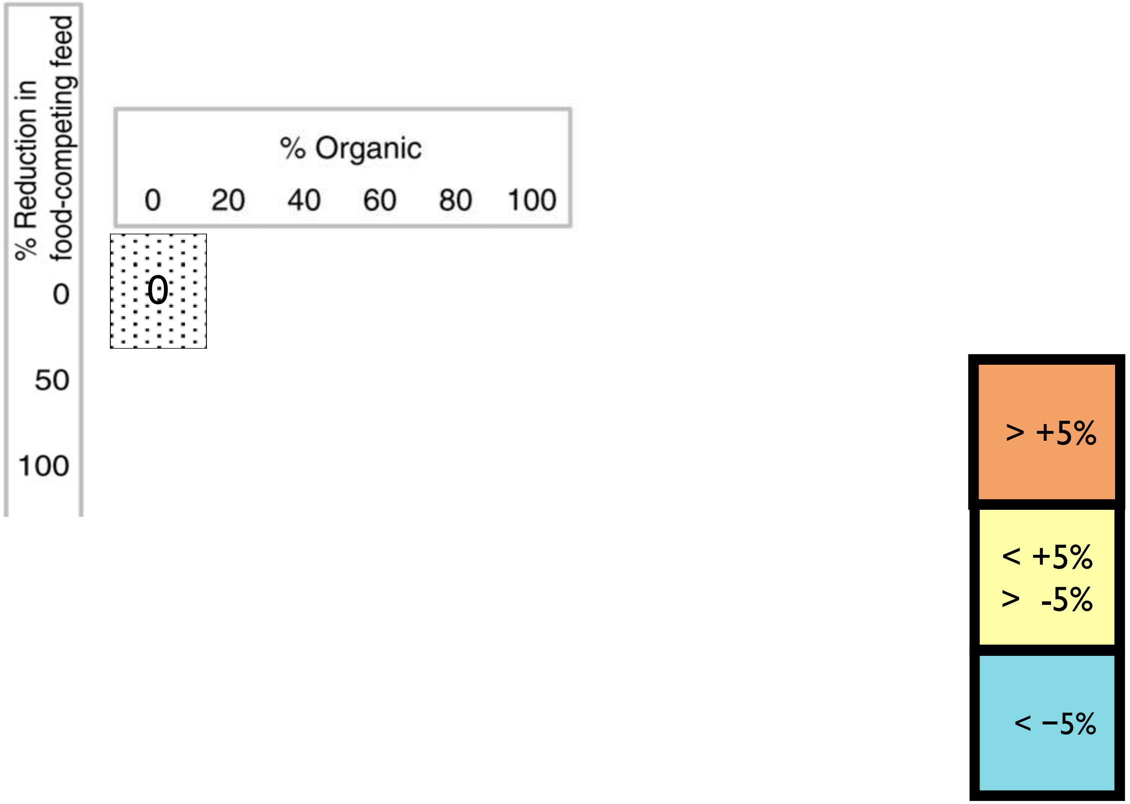




Galloway et al. 2021, SRC 2023, plus eigene Darstellung



Muller et al. 2017; Courtesy: R. Zürcher



Muller et al. 2017; Courtesy: R. Zürcher

% Reduction in food-competing feed	% Organic 0	20	40	60	80	100
0	0	5	10	17	25	33
50	–16	–12	–8	–4	2	8
100	–26	–24	–20	–16	–12	–8

> +5%

< +5%
> -5%

< −5%

Muller et al. 2017; Courtesy: R. Zürcher

% Reduction in food-competing feed	% Organic 0	20	40	60	80	100
0	0	5	10	17	25	33
50	−16	−12	−8	−4	2	8
100	−26	−24	−20	−16	−12	−8

> +5%

< +5%
> -5%

< −5%

Muller et al. 2017; Courtesy: R. Zürcher

Climate change impact on yields

Zero | Medium | High

% Organic (Zero climate change impact)

% Wastage reduction	% Reduction in food-competing feed	0	20	40	60	80	100
0	0	0	5	10	17	25	33
0	50	−16	−12	−8	−4	2	8
0	100	−26	−24	−20	−16	−12	−8
25	0						
25	50						
25	100						
50	0						
50	50						
50	100						

> +5%

< +5%
> -5%

<−5%

Muller et al. 2017; Courtesy: R. Zürcher

Climate change impact on yields

% Wastage reduction	% Reduction in food-competing feed	Zero: % Organic 0	20	40	60	80	100	Medium: % Organic 0	20	40	60	80	100	High: % Organic 0	20	40	60	80	100
0	0	0	5	10	17	25	33												
	50	–16	–12	–8	–4	2	8												
	100	–26	–24	–20	–16	–12	–8												
25	0	–6	–1	5	10	18	26	14	20	25	32	40	48	39	42	45	50	56	61
	50	–22	–18	–13	–8	–4	–2	–4	0	5	9	14	21	18	20	22	25	27	32
	100	–30	–27	–25	–21	–17	–13	–14	–11	–8	–5	–1	4	6	7	8	8	10	13
50	0																		
	50																		
	100																		

> +5%

< +5%
> -5%

<−5%

Muller et al. 2017; Courtesy: R. Zürcher

Climate change impact on yields

% Wastage reduction	% Reduction in food-competing feed	Zero: % Organic 0	20	40	60	80	100	Medium: % Organic 0	20	40	60	80	100	High: % Organic 0	20	40	60	80	100
0	0	0	5	10	17	25	33												
	50	–16	–12	–8	–4	2	8												
	100	–26	–24	–20	–16	–12	–8												
25	0	–6	–1	5	10	18	26	14	20	25	32	40	48	39	42	45	50	56	61
	50	–22	–18	–13	–8	–4	–2	–4	0	5	9	14	21	18	20	22	25	27	32
	100	–30	–27	–25	–21	–17	–13	–14	–11	–8	–5	–1	4	6	7	8	8	10	13
50	0																		
	50																		
	100																		

–1

> +5%

< +5%
> -5%

<−5%

Muller et al. 2017; Courtesy: R. Zürcher

Climate change impact on yields

% Wastage reduction	% Reduction in food-competing feed	Zero: % Organic 0	20	40	60	80	100	Medium: % Organic 0	20	40	60	80	100	High: % Organic 0	20	40	60	80	100
0	0	0	5	10	17	25	33	21	26	33	40	47	57	46	50	54	58	64	71
	50	−16	−12	−8	−4	2	8	2	7	10	16	22	27	25	26	29	32	35	40
	100	−26	−24	−20	−16	−12	−8	−9	−6	−3	1	5	9	12	13	14	15	17	20
25	0	−6	−1	5	10	18	26	14	20	25	32	40	48	39	42	45	50	56	61
	50	−22	−18	−13	−8	−4	−2	−4	0	5	9	14	21	18	20	22	25	27	32
	100	−30	−27	−25	−21	−17	−13	−14	−11	−8	−5	−1	4	6	7	8	8	10	13
50	0	−11	−7	−1	5	11	20	8	13	18	25	32	40	30	34	38	42	47	53
	50	−25	−23	−19	−14	−9	−4	−9	−6	−2	3	8	14	10	12	15	17	21	25
	100	−35	−32	−29	−25	−22	−18	−19	−17	−13	−10	−7	−3	−1	0	1	3	4	7

> +5%
< +5% > -5%
<−5%

Muller et al. 2017; Courtesy: R. Zürcher

Climate change impact on yields

% Wastage reduction	% Reduction in food-competing feed	Zero: % Organic 0	20	40	60	80	100	Medium: % Organic 0	20	40	60	80	100	High: % Organic 0	20	40	60	80	100
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	50	−16	−12	−8	−4	2	8	2	7	10	16	22	27	25	26	29	32	35	40
	100	−26	−24	−20	−16	−12	−8	−9	−6	−3	1	5	9	12	13	14	15	17	20
25	0	−6	−1	5	10	18	26	14	20	25	32	40	48	39	42	45	50	56	61
	50	−22	−18	−13	−8	−4	−2	−4	0	5	9	14	21	18	20	22	25	27	32
	100	−30	−27	−25	−21	−17	−13	−14	−11	−8	−5	−1	4	6	7	8	8	10	13
50	0	−11	−7	−1	5	11	20	8	13	18	25	32	40	30	34	38	42	47	53
	50	−25	−23	−19	−14	−9	−4	−9	−6	−2	3	8	14	10	12	15	17	21	25
	100	−35	−32	−29	−25	−22	−18	−19	−17	−13	−10	−7	−3	−1	0	1	3	4	7

> +5%

< +5% > -5%

<−5%

Muller et al. 2017; Courtesy: R. Zürcher

Climate change impact on yields

% Wastage reduction	% Reduction in food-competing feed	Zero: % Organic 0	20	40	60	80	100	Medium: % Organic 0	20	40	60	80	100	High: % Organic 0	20	40	60	80	100
0	0	0	5	10	17	25	33	21	26	33	40	47	57	46	50	54	58	64	71
0	50	−16	−12	−8	−4	2	8	2	7	10	16	22	27	25	26	29	32	35	40
0	100	−26	−24	−20	−16	−12	−8	−9	−6	−3	1	5	9	12	13	14	15	17	20
25	0	−6	−1	5	10	18	26	14	20	25	32	40	48	39	42	45	50	56	61
25	50	−22	−18	−13	−8	−4	−2	−4	0	5	9	14	21	18	20	22	25	27	32
25	100	−30	−27	−25	−21	−17	−13	−14	−11	−8	−5	−1	4	6	7	8	8	10	13
50	0	−11	−7	−1	5	11	20	8	13	18	25	32	40	30	34	38	42	47	53
50	50	−25	−23	−19	−14	−9	−4	−9	−6	−2	3	8	14	10	12	15	17	21	25
50	100	−35	−32	−29	−25	−22	−18	−19	−17	−13	−10	−7	−3	−1	0	1	3	4	7

Legend
> +5%
< +5% > -5%
<−5%

Muller et al. 2017; Courtesy: R. Zürcher

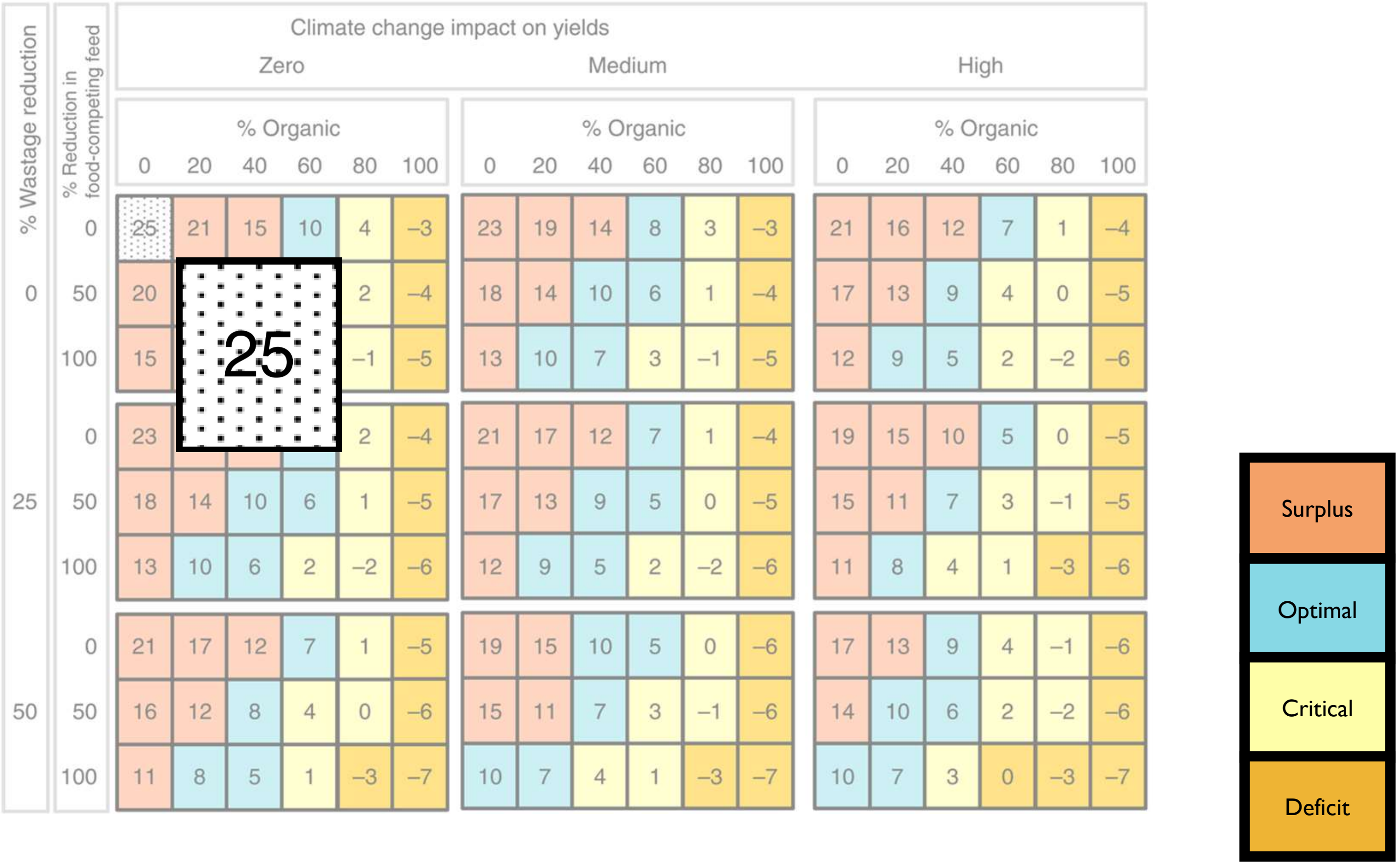
Nutrient supply in organic agriculture

- Not only the products, but also the fertilizer is produced on the fields.
- Challenge to provide sufficient nutrients, especially N and P

% Wastage reduction	% Reduction in food-competing feed	Climate change impact on yields: Zero — % Organic 0	20	40	60	80	100	Medium — % Organic 0	20	40	60	80	100	High — % Organic 0	20	40	60	80	100
0	0	25	21	15	10	4	–3	23	19	14	8	3	–3	21	16	12	7	1	–4
	50	20	16	12	7	2	–4	18	14	10	6	1	–4	17	13	9	4	0	–5
	100	15	11	7	3	–1	–5	13	10	7	3	–1	–5	12	9	5	2	–2	–6
25	0	23	19	14	8	2	–4	21	17	12	7	1	–4	19	15	10	5	0	–5
	50	18	14	10	6	1	–5	17	13	9	5	0	–5	15	11	7	3	–1	–5
	100	13	10	6	2	–2	–6	12	9	5	2	–2	–6	11	8	4	1	–3	–6
50	0	21	17	12	7	1	–5	19	15	10	5	0	–6	17	13	9	4	–1	–6
	50	16	12	8	4	0	–6	15	11	7	3	–1	–6	14	10	6	2	–2	–6
	100	11	8	5	1	–3	–7	10	7	4	1	–3	–7	10	7	3	0	–3	–7

> 10kg/ha	Surplus
between 10 and 5kg/ha	Optimal
between +5 and -5 kg/ha	Critical
<-5kg/ha	Deficit

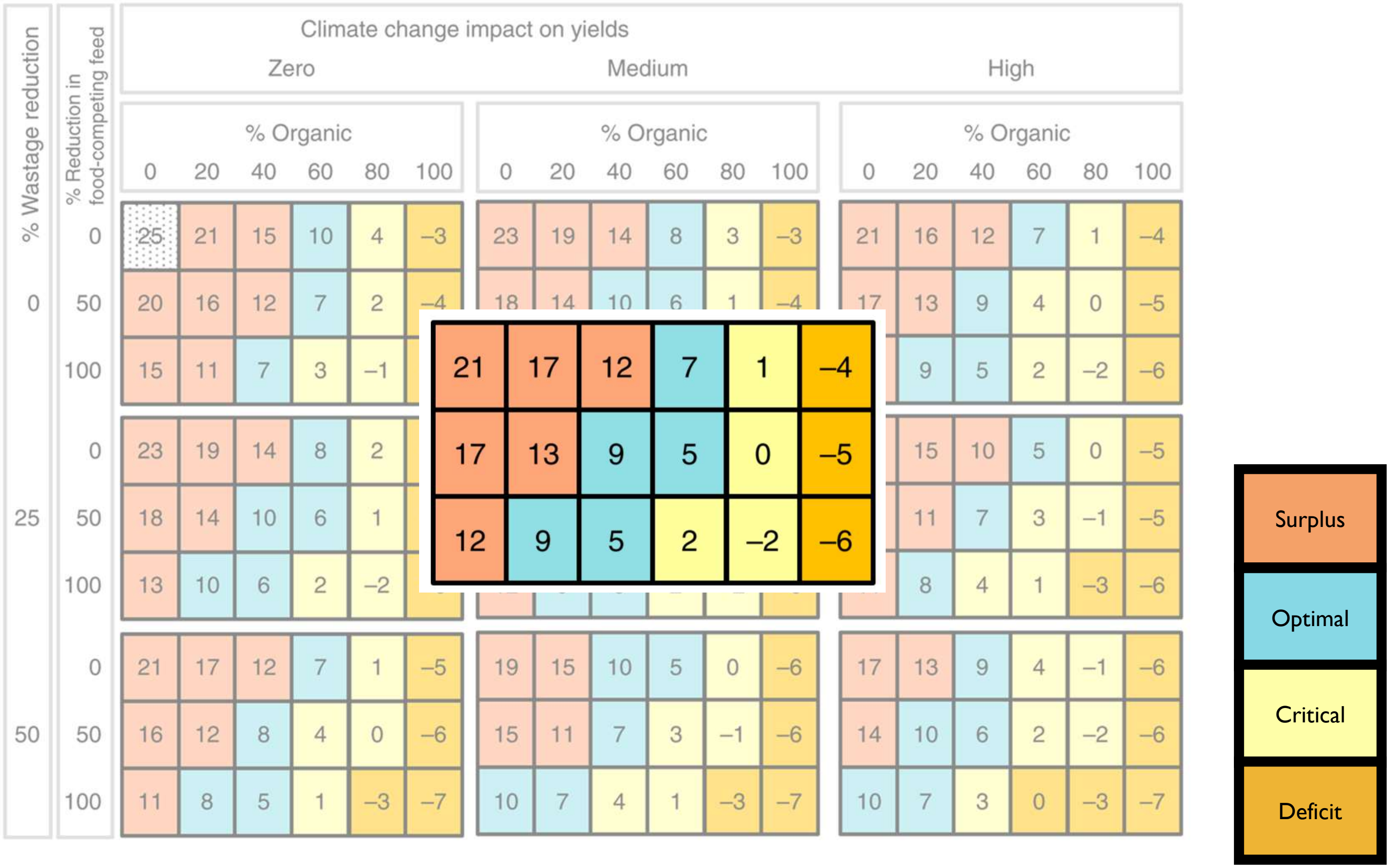
Muller et al. 2017; Courtesy: R. Zürcher



% Wastage reduction	% Reduction in food-competing feed	Zero: % Organic 0	20	40	60	80	100	Medium: % Organic 0	20	40	60	80	100	High: % Organic 0	20	40	60	80	100
0	0	25	21	15	10	4	–3	23	19	14	8	3	–3	21	16	12	7	1	–4
	50	20	[illegible]	[illegible]	[illegible]	2	–4	18	14	10	6	1	–4	17	13	9	4	0	–5
	100	15	[illegible]	[illegible]	[illegible]	–1	–5	13	10	7	3	–1	–5	12	9	5	2	–2	–6
25	0	23	[illegible]	[illegible]	[illegible]	2	–4	21	17	12	7	1	–4	19	15	10	5	0	–5
	50	18	14	10	6	1	–5	17	13	9	5	0	–5	15	11	7	3	–1	–5
	100	13	10	6	2	–2	–6	12	9	5	2	–2	–6	11	8	4	1	–3	–6
50	0	21	17	12	7	1	–5	19	15	10	5	0	–6	17	13	9	4	–1	–6
	50	16	12	8	4	0	–6	15	11	7	3	–1	–6	14	10	6	2	–2	–6
	100	11	8	5	1	–3	–7	10	7	4	1	–3	–7	10	7	3	0	–3	–7

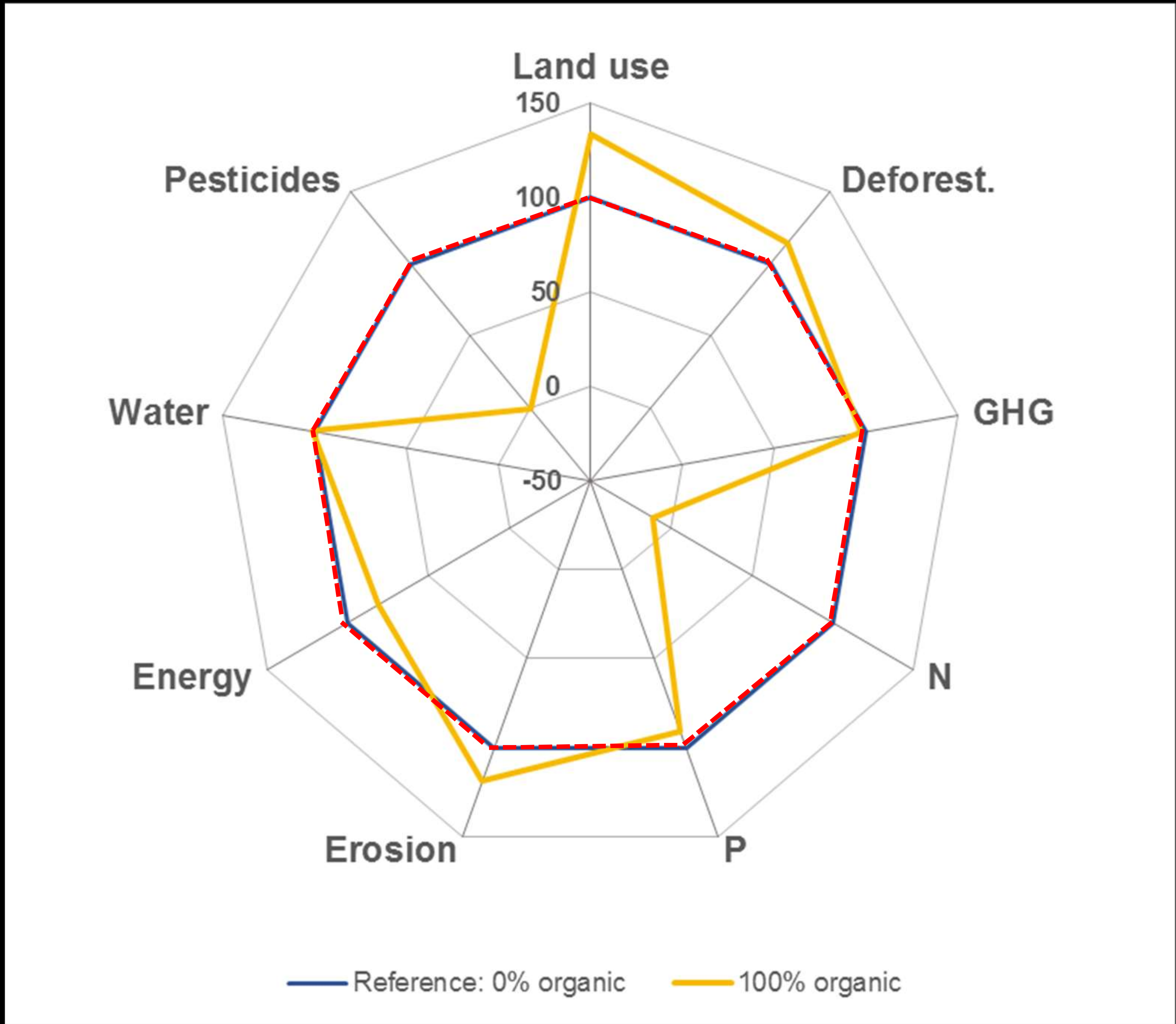
Climate change impact on yields

Muller et al. 2017; Courtesy: R. Zürcher



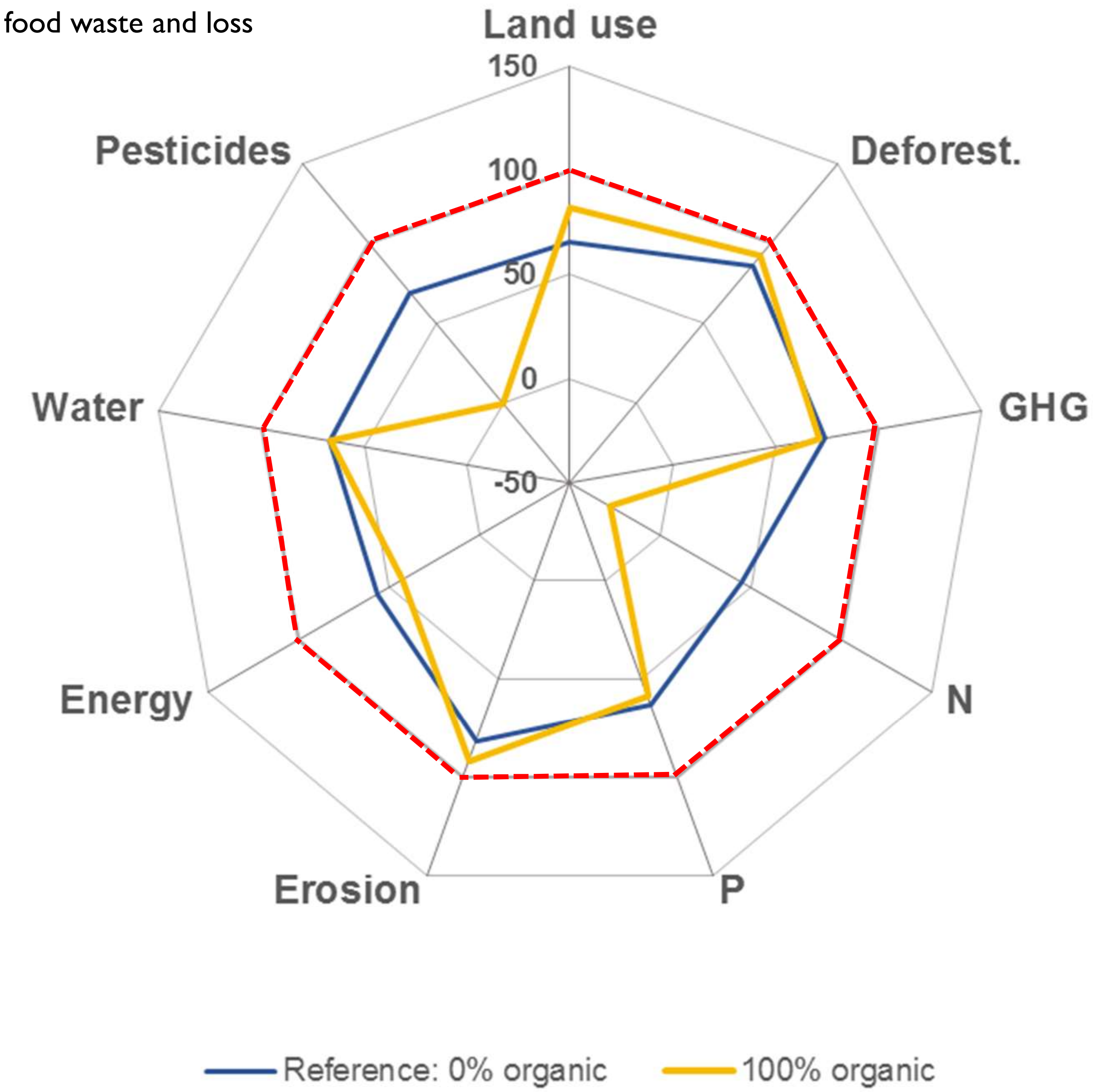
Muller et al. 2017; Courtesy: R. Zürcher

Other environmental impacts besides land use and nitrogen supply



Muller et al. 2017

100% food competing feed
reduction
50% less food waste and loss



Muller et al. 2017

Climate change impact on yields

% Wastage reduction	% Reduction in food-competing feed	Zero: % Organic 0	20	40	60	80	100	Medium: % Organic 0	20	40	60	80	100	High: % Organic 0	20	40	60	80	100
0	0	0	5	10	17	25	33	21	26	33	40	47	57	46	50	54	58	64	71
	50	−16	−12	−8	−4	2	8	2	7	10	16	22	27	25	26	29	32	35	40
	100	−26	−24	−20	−16	−12	−8	−9	−6	−3	1	5	9	12	13	14	15	17	20
25	0	−6	−1	5	10	18	26	14	20	25	32	40	48	39	42	45	50	56	61
	50	−22	−18	−13	−8	−4	−2	−4	0	5	9	14	21	18	20	22	25	27	32
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50	0	−11	−7	−1	5	11	20	8	13	18	25	32	40	30	34	38	42	47	53
	50	−25	−23	−19	−14	−9	−4	−9	−6	−2	3	8	14	10	12	15	17	21	25
	100	−35	−32	−29	−25	−22	−18	−19	−17	[illegible]	[illegible]	[illegible]	−3	−1	0	1	3	4	7

3

Climate change impact on yields

% Wastage reduction	% Reduction in food-competing feed	Zero: % Organic 0	20	40	60	80	100	Medium: % Organic 0	20	40	60	80	100	High: % Organic 0	20	40	60	80	100
0	0	25	21	15	10	4	−3	23	19	14	8	3	−3	21	16	12	7	1	−4
	50	20	16	12	7	2	−4	18	14	10	6	1	−4	17	13	9	4	0	−5
	100	15	11	7	3	−1	−5	13	10	7	3	−1	−5	12	9	5	2	−2	−6
25	0	23	19	14	8	2	−4	21	17	12	7	1	−4	19	15	10	5	0	−5
	50	18	14	10	6	1	−5	17	13	9	5	0	−5	15	11	7	3	−1	−5
	100	13	10	6	2	−2	−6	12	9	5	2	−2	−6	11	8	4	1	−3	−6
50	0	21	17	12	7	1	−5	19	15	10	5	0	−6	17	13	9	4	−1	−6
	50	16	12	8	4	0	−6	15	11	7	3	−1	−6	14	10	6	2	−2	−6
	100	11	8	5	1	−3	−7	10	7	[illegible]	[illegible]	[illegible]	−7	10	7	3	0	−3	−7

3

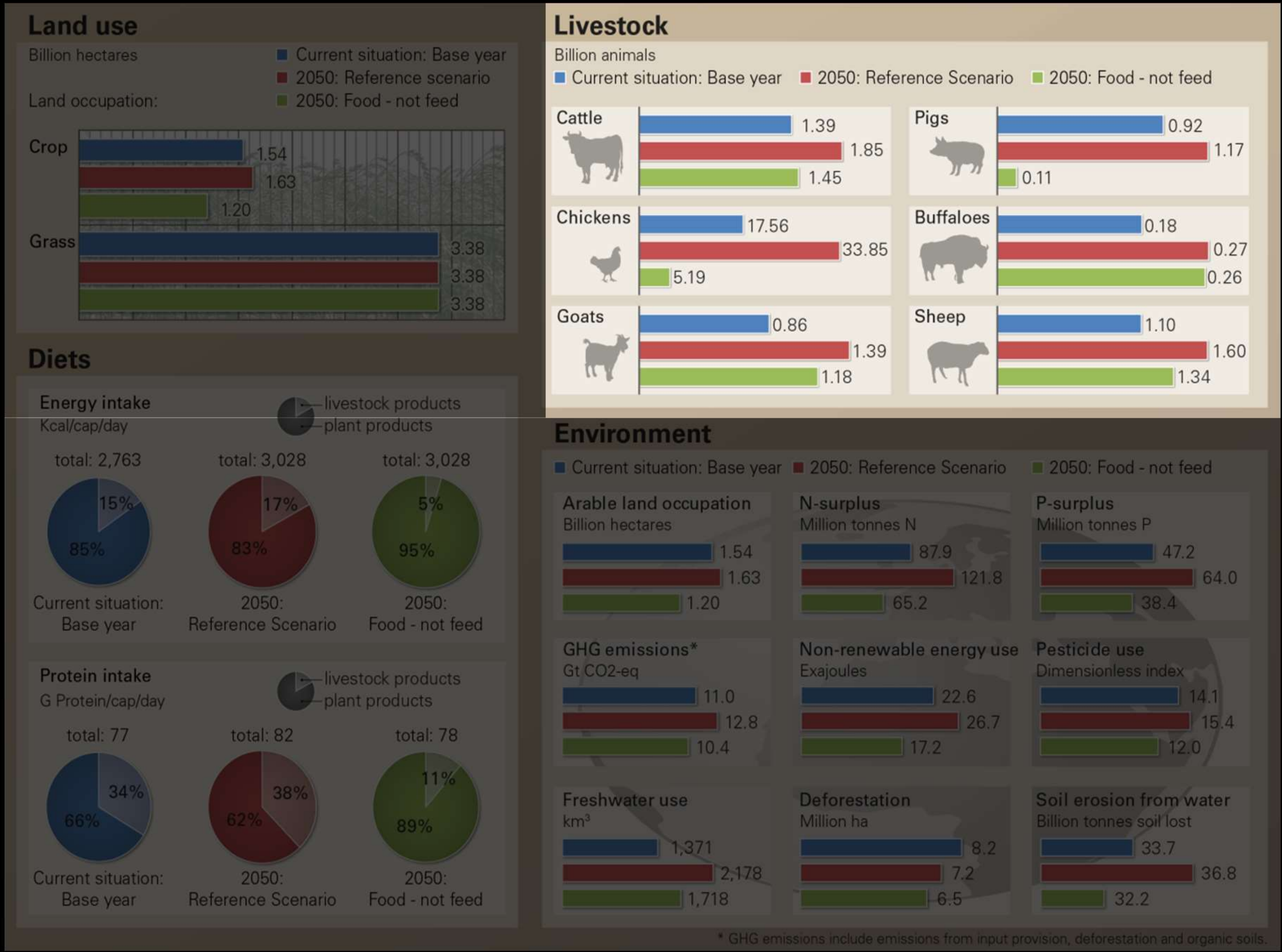
Muller et al. 2017; Courtesy: R. Zürcher

We know what to do for
being able to build on
NBS/agroecology
for sustainable food systems:

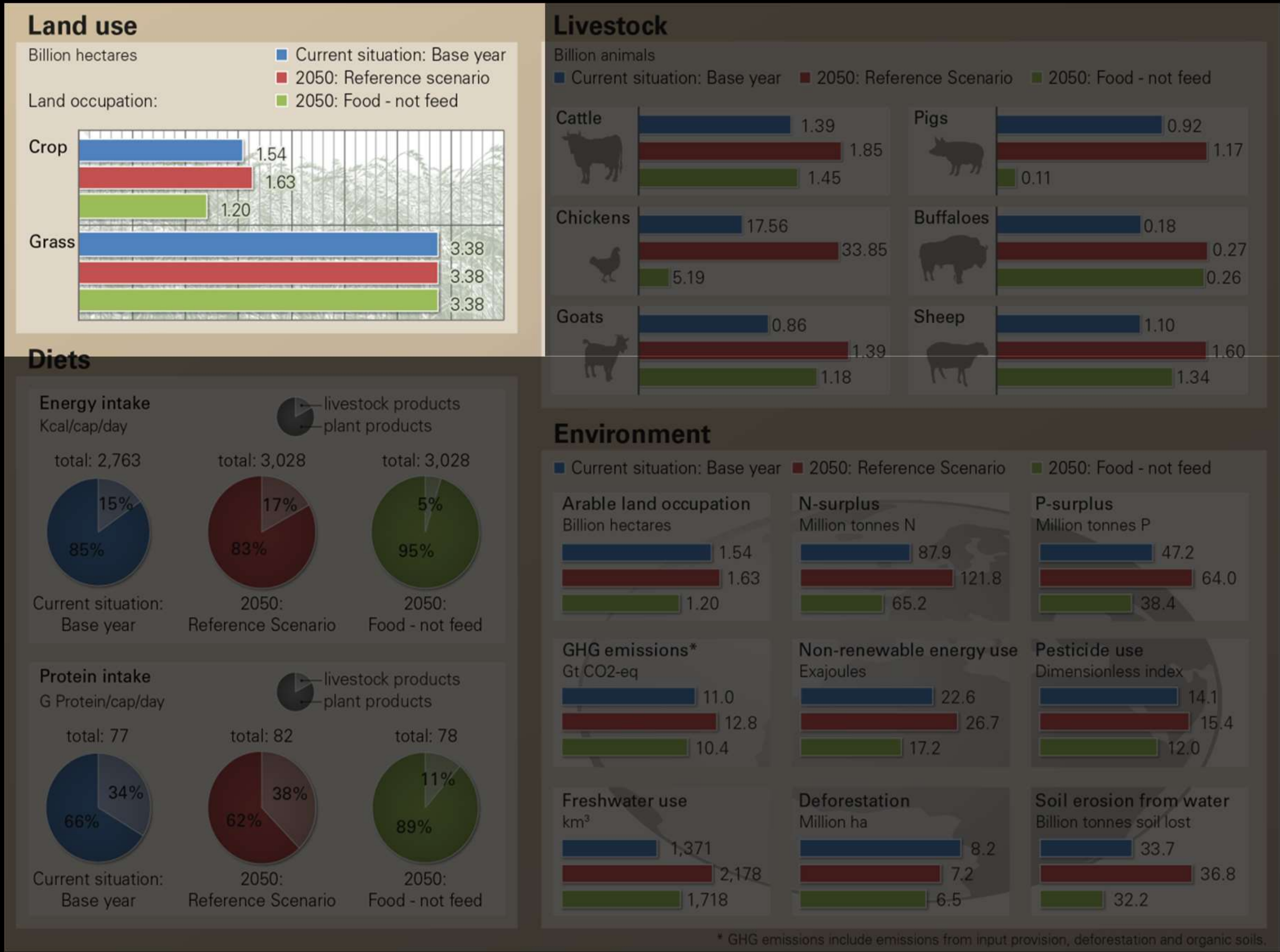
Size of the food system

- less waste and losses
- less feed from cropland
- less animals
- (less fossil energy)

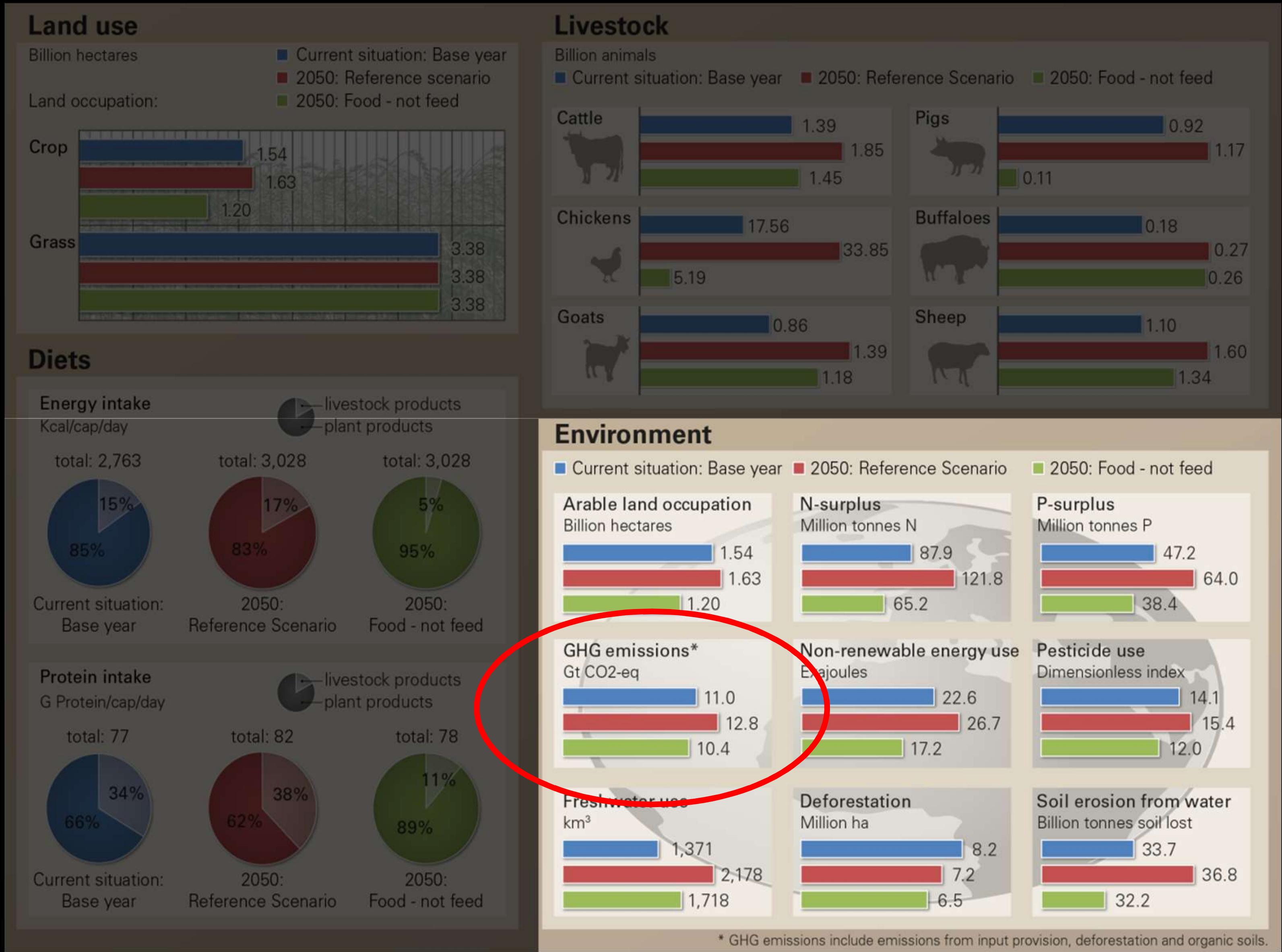
- less nitrogen
- less pesticides



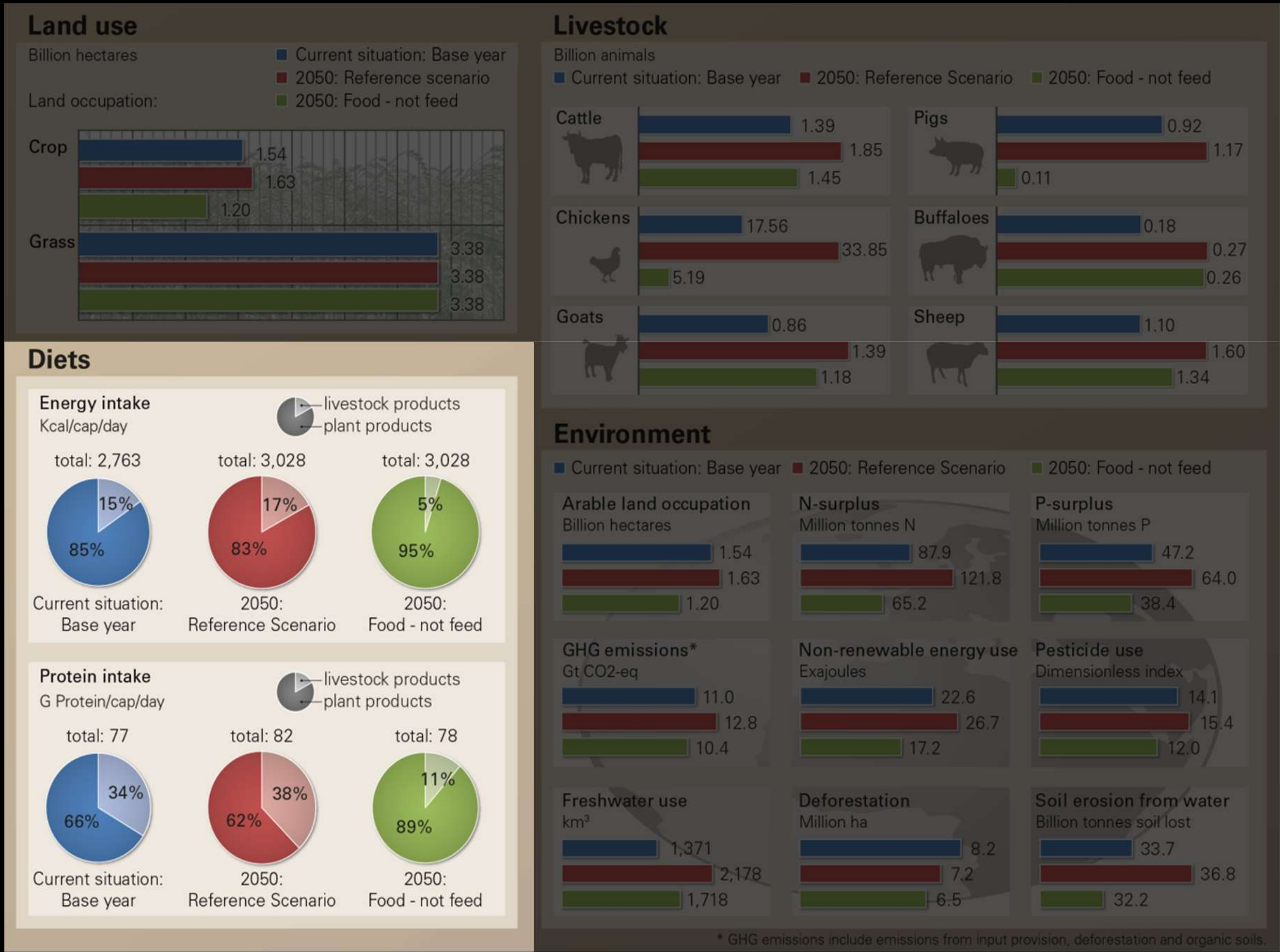
Schader et al. 2015



Schader et al. 2015



Schader et al. 2015



Schader et al. 2015

Option space and scenarios

- How to tell the story
- The bio-physical models we use allow to line out the option space of future agriculture and food systems
- The **option space** is the totality of all options that emerge from combining different levels along a number of different key dimensions, e.g.
  - Yields
  - Share of organic production
  - Level of reduction in food-competing feed for animals
  - Level of food waste reduction
  - Diets
  - GHG mitigation goals
  - Etc.

Option space and scenarios

- Each option in the option space can then be assessed according to their performance regarding various indicators, such as e.g.
  - Land use
  - Deforestation
  - Nitrogen surplus
  - GHG emissions
  - Biodiversity pressures
  - etc.

Option space and scenarios

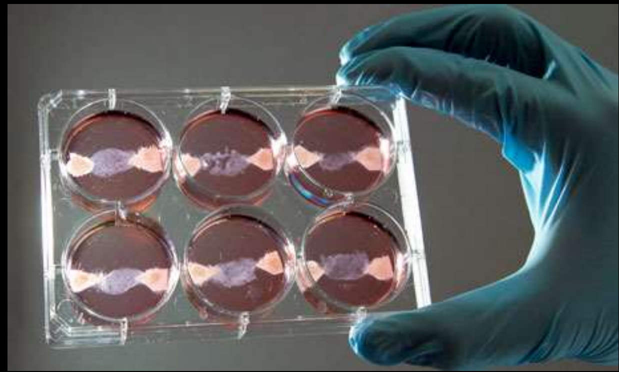
- **Scenarios** are certain options which we amend by a detailed description of which socio-economic dynamic may drive them, e.g. regarding:
  - policies
  - preferences
  - economic development
  - etc.
- Scenarios are thus telling selected stories/narratives within these special options in the option space

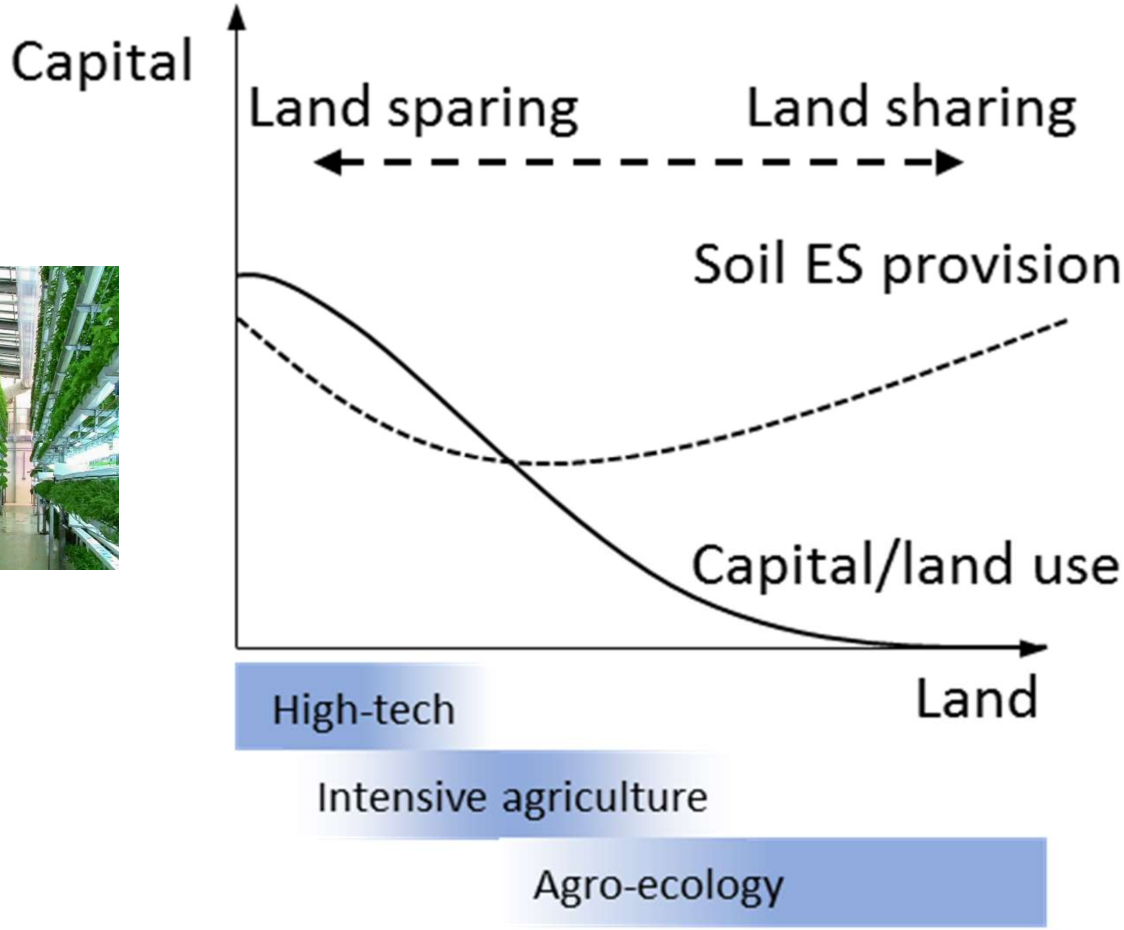
Policy and decision support

- We know what to do for being able to build on for sustainable food systems
- Which role for food system modelling results in policy and decision support?

- Focus on trade-offs and synergies

NBS vs. Other, technical approaches





Muller et al, 2017b

Technical details

- Generic structure of SOLm generated in R/excel and stored in SQLite

- Original data taken from various sources,
  - stored in excel and then loaded to R or
  - directly loaded to R (e.g. FAOSTAT)
- Data processing, preparation in R – keep as raw as possible
- Stored in SQLite, linked to the generic structure

Technical details

- Scenario files
  - load data from SQLite
  - do parameter and other choices and assumptions as needed
  - transform into the form required by the core model

- Core model files:
  - Derive domestically available quantities and their utilization from production unit numbers
  - Derive production unit numbers and yields if not provided at the beginning
  - Calculate outputs and impacts

Technical details

- Post processing
  - Output files
  - Figures and tables
  - Etc.

Technical details

- Core entities
  - **Production Units**:
    - Convert inputs into outputs (“hectare of wheat”, “dairy production unit”
    - Have some internal structure (herd structure, crop rotation)
  - **Commodities**: Outputs from PUs plus commodities derived via processes along the commodity tree
  - **Processes**: convert one commodity in a number of others (e.g. wheat grain into wheat flour, bran, germ)

Technical details

- Numbers of PUs
- Yields of PUs: Output per PU

- Shares of processes
- Extraction rates of processes

- Utilization of commodities

- Allocation of commodities as inputs to PUs:
  - fertilizer
  - feeding rations

« adrian.mueller › pilotmodul_SOLmR › For presentation

"For presentation" durchsuchen

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FeedingRations_BasicData.xlsx	01.04.2024 09:38	Microsoft Excel-A...	43 KB
HerdStructures_BasicData.xlsx	29.03.2024 15:56	Microsoft Excel-A...	21 KB
ProductionUnits_BasicData.xlsx	27.03.2024 11:53	Microsoft Excel-A...	231 KB
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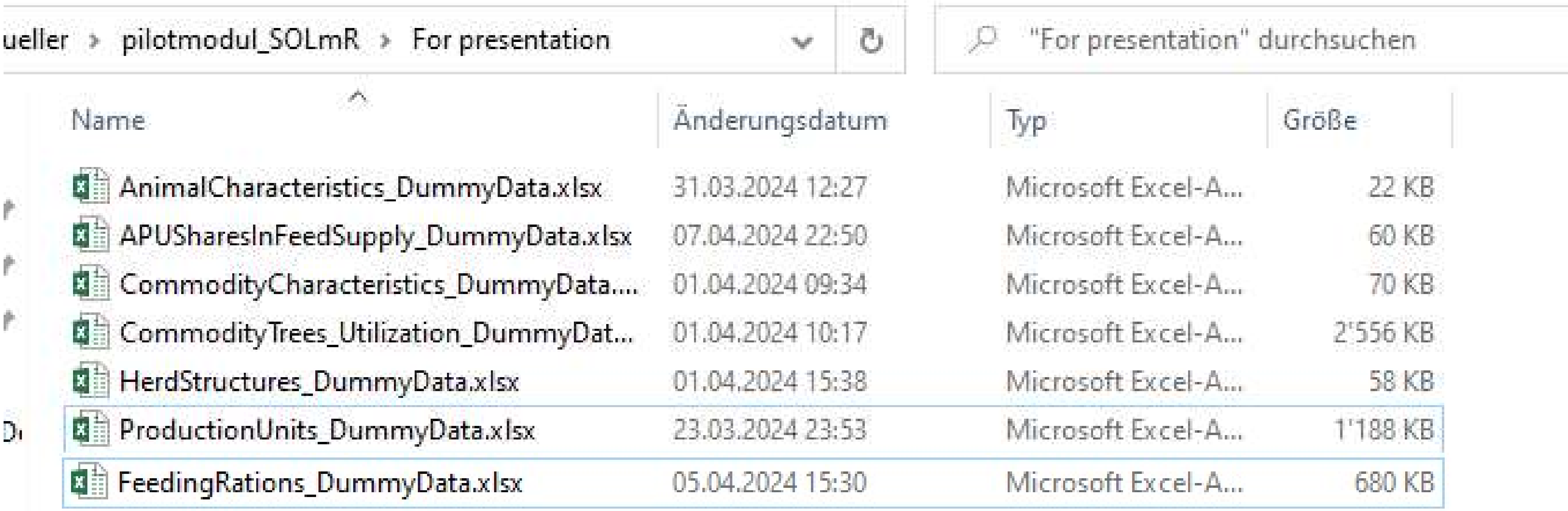
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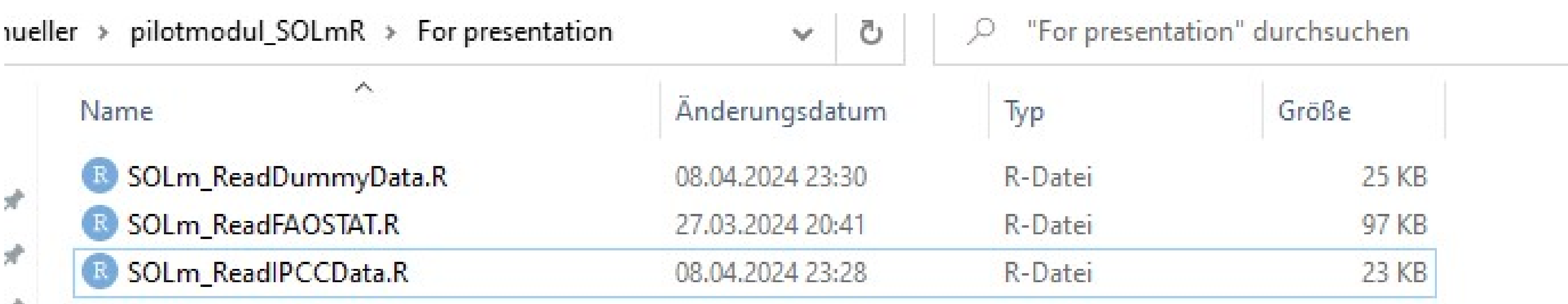
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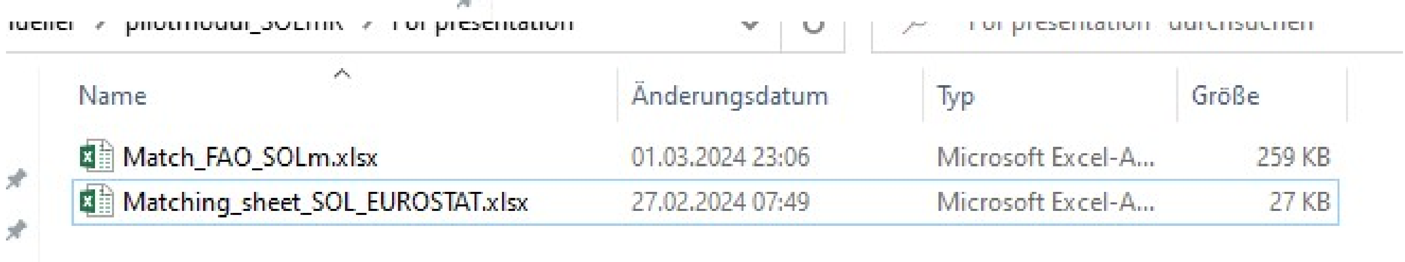
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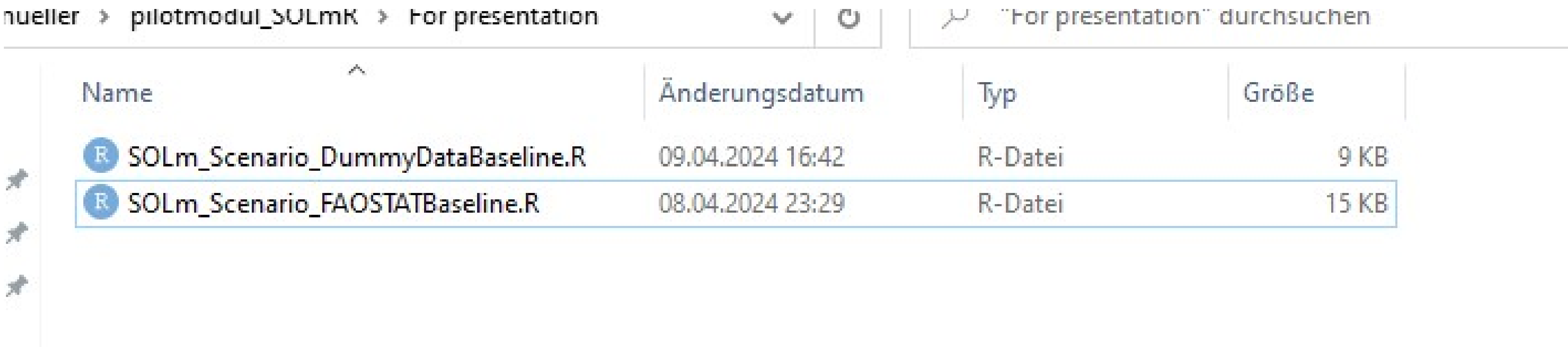
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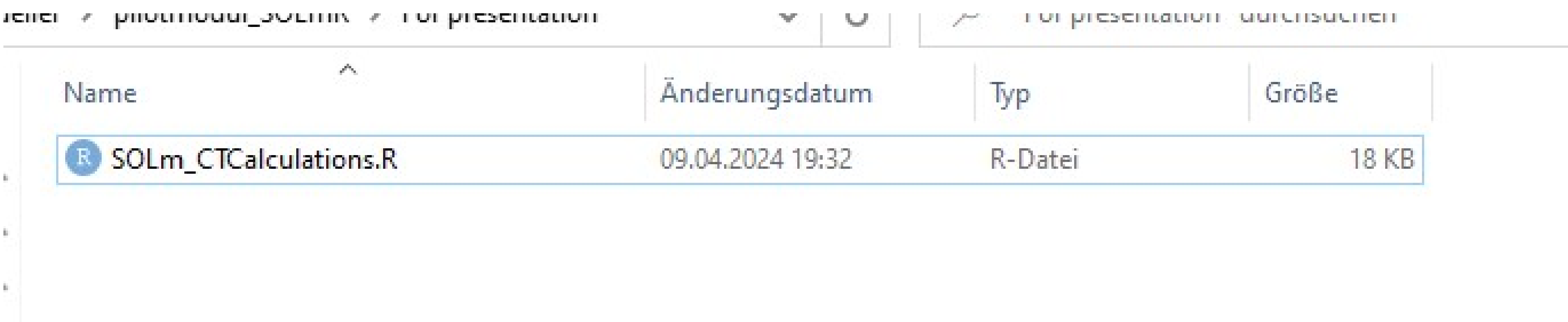
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Concluding remarks and questions

- Option spaces
- Scenarios

- Production Units
- Commodities
- Processes

- Number of PUs
- Outputs and Yields of PUs
- Internal structure of PUs: herd, crop rotation
- Share and extraction rates of processes
- Input allocation to PUs: fertilizer, feeding rations

References

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